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Coronavirus lockdown and virus suppression: An international analysis

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A R T I C L E I N F O

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A B S T R A C T

This paper analyses the effect of lockdown against the coronavirus which is one of the fastest growing threats in the world. We focus on three categories of lockdown and group four continents, Asia, America, Europe, and Africa together to assess the effectiveness of such a measure to contain the virus. We also look at a number of variables linked to the spread of the virus to determine the factors affecting the growth of new confirmed cases. We show evidence that countries in Europe are more likely to impose a national lockdown than any other continent. For the empirical analysis, we undertake the cross-sectional regression model, logistic regression model and logistic growth curve as a method to apply the data collected over the period March to June 2020 as this is the data available at the time this paper is composed. The empirical results of this paper indicate that countries which impose the strictest form of lockdown will result in a reduction in growth of new confirmed cases.

1. Introduction to research background

Since China imposed the coronavirus lockdown in the city of Wuhan in the Hubei province on the 23rd January 2020, many countries in Asia and Europe have followed China's example to impose a lockdown in a bid to stop coronavirus outbreaks. It follows that areas with high infection rates are under lockdown or have been subjected to restrictions. These include the closure of outdoor spaces, cancelling of events, restriction in the number of households eligible to meet and the closure of specific premises. These measures have been identified as a means to curb the spread of the virus.

This paper focuses on three categories of lockdown on a global scale to assess the effectiveness of such a measure to contain the virus. In particular, we focus on national, local and moderate lockdown which various countries have implemented. According to British Broadcasting Corporation[1] by Dunford et al. (2020), over 70% of countries in Europe went into national lockdown in March 2020. Lockdown has led to less people being infected by the coronavirus and has reversed the epidemic growth (Ferguson et al., 2020). Although lockdown has been considered an effective method to suppress the virus before a vaccine is discovered, the implementation of lockdown is complex due to its economic, political, and social effects (Auray and Eyquem, 2020; Eichenbaum et al, 2020; Gros, 2020; Vinceti et a1., 2020). In analysing the advantages and disadvantages on implementing lockdown, Melnick and Ioannidis (2020) suggest that the only way to prevent further catastrophic spread of the virus is by imposing lockdown.

At the outset, many countries mistakenly perceived the threat of the virus as low, associating the symptoms and casualty effect with the likes of a common cold. The appreciation to this severity was only gathered at a later stage once the virus had already multiplied in countries such as China, South Korea, Italy and the United Kingdom which saw a sharp incline in the number of confirmed cases. Appropriate control measures to the risk assessment carried out were slow to take shape. According to Rogers (2003), "an innovation is an idea, practice, or object that is perceived as new to an individual or another unit of adoption." In order to suppress the virus and flatten the curve, innovative measures such as lockdown and social distancing have been enforced. This in turn has led to a change in lifestyle and working environment in the general public which has affected various sectors such as hospitality and education.

It is widely evident that Covid-19 is a new illness that has swept the world by storm. Not only does it carry a high infection rate, but the coronavirus has proven to have dire consequences on the lungs and respiratory systems in the human body. Subsequently, this has in some instances led to long term health issues, and death. Much like the phrase coined from Darwin, the "survival of the fittest" theory is applicable to the virus which has proven to thrive much fairer when certain factors

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[1] British Broadcasting Corporation collected 157 countries to classify the coronavirus containment measures from recommended restricted movement for some or all of citizens in a country to the strictest measure to lock down the entire country. The classification consists of localised recommendations, localised lockdown, national recommendations and national lockdown.

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prevail. This paper will analyse these factors and assess the effectiveness of lockdown. Various risk control measures[2] have been implemented to reduce the spread such as shielding, self-isolation, social distancing policies and the development of testing and contact tracing. The reproduction number, R is a way of calculating the virus's ability to spread the disease. At the outset, every infected person was estimated to pass the virus to around 2–2.5 people (Gros et al., 2020; Zhang et al., 2020). The United States have been by far the hardest-hit country in the world in both the number of cases and deaths. Increasingly, the primary approach adopted by countries in Europe, Asia and America, has been to impose a category of lockdown and restrictions, all in an effort to curb the infection rate and limit the disease transmission.

In this paper, we focus on three research methods, the cross-sectional regression model, logistic growth curve analysis and logistic regression model in our analysis. The first stage in our analysis ascertains and compares the different levels of lockdown implemented on a global scale. We focus on empirical evidence gathered in the period March to June 2020 as this is the data accessible at the time this paper is composed. This is when most countries across the world began to impose lockdown. In addition, we examine the key factors affecting the growth of new confirmed cases. The second stage investigates whether the decision across four continents to implement national lockdown had any widespread merit. We look to analyse whether this decision has led to a significant decrease in growth and subsequently cases during the period, March to June 2020. Lastly, we employ the logistic growth curve analysis to major European countries to confirm the validity of adopting national lockdown in March when the virus rapidly surged.

This paper investigates several determinants to identify the relationship between new cases and key factors. This includes the total number of cases, underlying health conditions, population, gross domestic product (GDP) per capita, and the number of hospital beds. Our findings show that there is a direct correlation between the total number of cases and the growth in which these new cases arise. This indicates the importance of the reproduction number contributing to the virus spread. The GDP variable is a factor but is shown not to be significant in the all regression equations. It has a negative relationship between new cases and GDP. This finding indicates that countries inputting more financial resources are likely to reduce the spread of the virus. As a result, it will come to no surprise that a national lockdown decision has economic and financial consequences. On the other hand, underlying health conditions such as cardiovascular disease and diabetes have a positive relationship to new cases. Investigations are made into the growth trajectory of European countries which have imposed a national lockdown. Our evidence shows that as the growth curve of the Covid-19 infection rate slows due to national lockdown, so does the number of new confirmed cases. The logistic model is used to model the growth trajectory of the virus in Europe. This model will provide an examination on the effectiveness of this measure imposed by the majority of European countries.

Ultimately, our findings show that the speed in which the virus affects the world is unprecedented. The rate of infection is exponential and the magnitude in which the virus affects countries varies in both incubation period, morality rate and confirmed cases. Subsequently, this has had an interesting effect on the category of lockdown and restrictions adopted by various countries. Our findings show that in Europe, imposing a national lockdown was most popular and most effective compared to other measures. Our results also show that new cases arising in May 2020 in Europe grew but it grew less than the new confirmed cases in April 2020.

The remainder of this paper is structured as follows, literature review, data collection and research methods. The next section of this paper consists of a literature review which consists of an overview of the Severe Acute Respiratory Syndrome (later referred to as SARS) and Covid-19 and compares the contemporary issues on lockdown decisions. Section 3 covers data and research methods including cross-sectional regression equations. In this section, we focus on factors affecting the spread of the virus, and use the logistic regression model to examine the lockdown decision, and the logistic growth model by Fisher and Pry (1971), Meyer (1994), and Meyer et al. (1999) to assess the growth trajectory and daily growth rate in Europe. Section 4 presents empirical findings and analysis and finally, we detail our concluding remarks in Section 5.

2. Literature review

2.1. Overview of SARS and Covid-19

SARS and Covid-19 are genetically related and belong to the same virus group, coronaviruses. However, while they relate, the two viruses are fundamentally different. Although this paper recognises that the illness SARS is not a direct replica of the strain, Covid-19 coronavirus, it does provide extensive insight into how different governments have coped with epidemics of this nature. Emphasis is on the suppression tactics adopted by the government and how the disease epidemic adversely impacts the financial system on the allocation of risk bearing and management of risk.

By way of background, the first reported SARS case was in China, in November 2002. This quickly escalated to 26 countries with more than 8000 people diagnosed with the virus and a death rate of 774 (Lee and McKibbin, 2004; Oshitani, 2005). The SARS epidemic spread predominantly in China, Taiwan, Hong Kong, Singapore, and Canada in comparison to the United Kingdom, which reported four probable cases. The SARS epidemic taught us the importance of medicinal safeguards, technological advancement through the use of an epidemic prevention network, increased awareness of society's understanding of infectious diseases, and the implementation of infection control measures (Oshitani, 2005; Wilder-Smith et al., 2020).

The use of face coverings to prevent the spread of infection has been a topic of debate amongst scholars. Studies (e.g. MacIntyre et al. 2009; Lyu and Wehby, 2020) show that many countries in Asia readily complied with this form of protection whilst in western society, this has been faced with more resistance and hesitation. The World Health Organisation was initially reluctant to recommend the use of a face mask and only recommended the use of fabric face coverings to curb the spread of the infection. It was not until the 10th July 2020 that some countries such as Scotland, made face coverings mandatory in shops and in England on the 24th July 2020. This cultural issue has challenged the United Kingdom and the United States in particular where it is now evident that face masks do have positive use against the spread of infection. This risk control measure is a direct result of the pandemic.

On the 22nd October 2020 the death rate of those effected with Covid-19 in the United Kingdom is more than 44,347 with a total of 810,467 confirmed cases and counting. Not surprisingly, recent research advocated by Wilder-Smith et al. (2020) emphasises how different the epidemic trajectory is between SARS and Covid-19. The latter has far exceeded the SARS epidemic.

2.2. Coronavirus spread and lockdown decisions

We have seen many countries throughout the world implement restrictions across different sectors to curb the spread of the virus. In particular, the hospitality sector has seen disastrous consequences where many pubs, cafes, restaurants have been forced to shut or have had restrictions imposed on them. In the education sector, many primary schools and secondary schools have closed, and a move away from face to face teaching to online learning has been implemented at universities. The transportation sector has seen a significant decrease in the number of people using public transport and aviation.

[2] The purpose of risk control is to reduce the reproduction number (R0) so that reproduction number (R0) is below 1. The R0 number is to quantify the ability of viruses to spread.

It comes to no surprise that implementing any lockdown decision is controversial as it will affect the well-being and economic welfare of the country and the people living there. However, this is all in an effort to slow the spread of the virus, prevent the health sector from being overwhelmed by the number of patients infected by this virus, and to buy time for a vaccine to be developed and distributed. Studies have shown that different forms of lockdown affect the infection rate (Gros, 2020; IMF, 2020). A massive decline in economic activity has hit many countries[3] along with an increase in unemployment rates (Auray and Eyquem, 2020; Eichenbaum et al, 2020; Gros, 2020; IMF, 2020). Gros (2020) debates the importance over lives saved over job losses. Gros et al. (2020) support strong risk control strategies which are likely to lower the infection rates and economic costs in containing the virus. However, the medical costs come at a steep price and are equivalent to about 14% of GDP, or over €1,500 billion (€1.5 trillion) for the EU. To put matters into perspective, in Germany, each case would cost on average, €50,000 which is about 100% of (annual) GDP per capita per infection. This is about two thirds of Spain's GDP per capita per case (Gros, 2020).

Meunier (2020) views the lockdown decisions made in France, Italy, Spain and the United Kingdom as having no adverse effect on the daily death growth rate when national lockdown is first implemented in these countries. Meunier (2020) goes on to suggest that social distancing measures have had approximately the same effect as police-enforced home containment policies. When these lockdown measures were implemented, the growth rate of daily deaths in the United Kingdom was at a constant slope. In contrast, the growth rate decreased in France, Italy, and Spain. Vinceti et al. (2020) collect mobile phone mobility data during the period 1st February 2020 to the 27th March 2020 to investigate the daily positive tests in Italy. Their findings show that the spread of the coronavirus largely depends on the degree of stringency and how extreme the lockdown restrictions are. As the degree of mobility reduces, this leads to a decrease in transmission. This data was collected when lockdown measures were first imposed following a peak in cases, taking into consideration nine to fourteen days later. As a consequence, the growth trajectory speeds up and then flattens as a result of these measures. Further, Vinceti et al. (2020) point out that the lag time of observed days between lockdown and the epidemic peak results due to the natural history of the disease and the incubation period. Kucharski et al. (2020) show that in China the reproduction number declined from 2.35 to 1.05 in one week before travel restrictions came into force on the 23rd January 2020. Further, Kucharski et al. (2020) find that the coronavirus transmission rate declined in Wuhan in late January 2020 as a result of these travel control measures and the implementation of local lockdown.

2.3. Factors affecting new cases

2.3.1. Types of lockdown

There are a number of factors that may affect the growth of new cases. Different lockdown restrictions can effectively lead to a reduction in the number of new cases. Ultimately, they can be summarised as follows; national lockdown, local lockdown and moderate lockdown. On the assumption that a country has a high number of confirmed cases or a rapid growth trend, it is then more likely to impose stronger measures. Consequently, it follows that if the strictest form of lockdown is adopted this will mean that its effectiveness outweighs that of the other lockdown measures and will succeed in significantly reducing the number of new cases.

2.3.2. The total number of confirmed cases

The number of current confirmed cases in a country is positively related to the number of new cases. As the number of total confirmed cases per million in a population increases, this will result in a rapid spread of the virus and an increase in new confirmed cases. The total number of confirmed cases represents a lagged variable. When the reproduction number is greater than 1, the new cases will increase exponentially. The slope coefficient may be used to indicate the level in which the virus spreads in a population and represents the reproduction rate. The slope coefficient was likely high until lockdown was lifted.

2.3.3. Underlying health conditions

According to the World Health Organisation, cardiovascular diseases are the number one cause of death globally, taking an estimated 17.9 million lives every year. According to the data collected from the Oxford Word Data Organisation of the pre-existing health conditions in China, those with cardiovascular disease are more vulnerable against the virus. Other health conditions such as diabetes, chronic respiratory diseases, hypertension, and cancer are all risk factors as well. We use cardiovascular disease and diabetes as a proxy in our data set. Researchers (Clark et al., 2020; Ferrar et al., 2020; Holman et al., 2020) have found that the case fatality rate from Covid-19 for those with an underlying health condition such as cardiovascular disease and diabetes run the risk of contracting the virus more easily. The consequences are much higher than those without. For instance, more than ten percent of people with cardiovascular disease have been diagnosed with Covid-19. This is compared to those without underlying health conditions. Ultimately, our findings will show that those with underlying conditions are more susceptible to the virus which in turn increases the number of hospital beds. This particular factor has a positive relationship to the number of new confirmed cases.

2.3.4. Hospital beds

There has been significant pressure on the health sector to cope with the surge in patients being admitted as a result of contracting the virus. The number of patients admitted and the capacity of hospitals in having enough beds and staff, is a factor in assessing the spread of the virus. Christen et al. (2020) highlight that the capacity in which a hospital may have to admit patients has a direct correlation to the number of new cases. Lifesaving treatment and health care are crucial instruments in stopping the virus from spreading further. If the number of patients outweighs the number of beds available in a hospital, then the virus will not be controlled and there will be an increase in new cases. The challenge here lies in testing and quarantining those with suspected cases of the virus and those positive for the virus. Therefore, it is likely that there is a negative relationship between the number of beds in a hospital and increase in new confirmed cases.

2.3.5. GDP per capita

GDP per capita is defined as the logarithm of GDP per capita and it can be used to control the level of economic development (Ashraf, 2020). There has been a negative effect on GDP and the rate of unemployment as a result of lockdown (IMF, 2020). This has indicated that there is an expensive economic cost attached to the measures taken by the government to curb the virus. Countries with a high level of income are able to offer stimulus packages to stabilise the financial market and adopt a partial or a national lockdown to suppress the virus spread (Ashraf, 2020). In this paper, we hypothesise that there is a negative relationship between GDP per capita and increase in new cases.

2.3.6. Population

In different age groups, we have seen the virus affects them differently. As a result, early data suggests that age is a factor in catching the virus and indeed, the severity of the symptoms associated with the virus. Ioannidis et al. (2020) find that people who are under the age of 65 are at a lower risk than those who are over that age in European countries.

[3] According to IMF (2020), the projected growth rate for real GDP for 2020 in most of European countries have been affected by the coronavirus outbreak. On average, there is a negative annual percentage change of 6.6% in Europe. The projected unemployment rate is 9.2% in 2020 while it was 6.6% in 2019.

Clark et al. (2020) find that people with more than one underlying health condition are at an increased risk of attracting the virus and having more severe symptoms. Therefore, a country with a rising ageing population is more likely to be at risk. We therefore find it reasonable to use a population variable as a defining factor. The size of a population in a country can be used to evaluate the risk associated with the infection rate and death rate across countries. Population is defined as the logarithm of a population. We use population to investigate whether different sizes of a country's population will lead to an increased infection rate.

3. Data and methodology

3.1. Data description

The dataset from "Our World in Data from Oxford Martin School" includes seven major continents Africa, Asia, Europe, North America, Oceania, and South America. Emphasis is on four continents, Asia, America, Europe, and Africa due to geographical and sample size consideration. A four-month period between March to June 2020 is analysed. The majority of countries imposed different levels of lockdown at the beginning of March 2020. These lockdown restrictions were thereafter eased in May and June 2020 (Born et al., 2020; Cresswell et al., 2020; Flaxman et al., 2020; Meunier, 2020). As a result, data is collected during this specific period to examine the effectiveness of different levels of lockdown.

Table 1 collects data from 123 countries and reviews the coronavirus pandemic between March to June 2020. Globally, the number of confirmed cases has risen exponentially from less than one hundred thousand cases in March to more than ten million cases in June. To put this into perspective, more than three million confirmed cases were recorded in April, when a month before that, the number was less than a million. In May, there was a further increase of around 2.9 million and in June, 4.2 million. The death toll increased as a result, and more than half a million deaths were recorded by June as a result of the pandemic. Among the continents, Europe experienced the fastest positive incline in the number of cases (Ferguson et al., 2020; Flaxman et al., 2020). In European countries, the peak was recorded in April and a steady increase in confirmed cases befell the following months of May and June. The death rate in Europe was highest in March among other continents which resulted in many European countries such as Austria, Italy, Spain, and the United Kingdom to impose a national lockdown (Flaxman et al., 2020). On the other hand, cases in America increased rapidly between April and June. In June, more than 5 million people contracted the virus,

Table 1
Summary statistics of coronavirus accumulated cases, deaths, and mortality rates across continents.

	March			April			May			June		
Asia	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality
Sum	153851	6634	0.0431	318822	14580	0.0457	691067	23985	0.0347	1501276	45002	0.0300
	(0.1924)	(0.1714)		(0.1017)	(0.0640)		(0.1146)	(0.0650)		(0.1461)	(0.0891)	
Mean	5305	229	0.0181	10994	503	0.0203	23830	827	0.0184	51768	1552	0.0174
SD	16702	781	0.0265	22785	1365	0.0222	44651	1843	0.0191	115586	3702	0.0168
Observations	704			870			899			870		
Countries	29			29			29			29		
Europe	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality
Sum	424372	27852	0.0656	1275078	132830	0.1042	1904368	172373	0.0905	2360419	189914	0.0805
	(0.5307)	(0.7196)		(0.4067)	(0.5830)		(0.3159)	(0.4671)		(0.2298)	(0.3758)	
Mean	12860	844	0.0288	38639	4025	0.0609	57708	5223	0.0648	71528	5755	0.0616
SD	26747	2378	0.0297	62476	8355	0.0484	97269	10455	0.0479	130790	11246	0.0467
Observations	961			990			1023			990		
Countries	33			33			33			33		
America	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality
Sum	188304	3678	0.0195	1291296	74443	0.0576	2841558	161307	0.0568	5216953	248433	0.0476
	(0.2355)	(0.0950)		(0.4119)	(0.3268)		(0.4713)	(0.4372)		(0.5078)	(0.4916)	
Mean	7846	153	0.0338	53804	3102	0.0548	118398	6721	0.0380	217373	10351	0.0363
SD	33437	644	0.0486	210914	12388	0.0546	367036	21565	0.0266	578010	27746	0.0274
Observations	533			720			744			719		
Countries	24			24			24			24		
Africa	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality
Sum	3621	87	0.0240	25614	896	0.0350	111848	2801	0.0250	343519	7895	0.0230
	(0.0045)	(0.0022)		(0.0082)	(0.0039)		(0.0186)	(0.0076)		(0.0334)	(0.0156)	
Mean	98	2	0.0370	692	24	0.0367	3023	76	0.0264	9284	213	0.0240
SD	235	7	0.0701	1231	64	0.0364	6308	181	0.0244	25574	613	0.0195
Observations	602			1110			1147			1110		
Countries	37			37			37			37		
World	Cases	Death	Mortality	Cases	Death	Mortality	Cases	Death	Mortality	Case	Death	Mortality
Sum	799674	38705	0.0484	3135127	227823	0.0727	6028737	368992	0.0612	10273406	505309	0.0492

• A confirmed case is defined as a person with laboratory confirmation of Covid-19 infection.
• The variables: cases, death and mortality are defined as follows
- cases are the number of accumulated confirmed cases;
- death is the number of accumulated deaths;
- mortality is the number of deaths divided by the number of confirmed cases.
• The variables in the first column are defined as follows:
- Sum is the sum of total confirmed cases or the number of deaths across countries in each continent at the end of each month;
- Mean is the average of total confirmed cases, deaths or mortalities across countries in each continent in each month and the valuation date of each month;
- SD is the standard deviation of total confirmed cases, deaths or mortalities across countries in each continent in each month and the valuation date of each month;
- Observations account for countries in each continent and days in each month;
- Countries denote to either Asia, Europe, America or Africa in the respective row.
• Summary statistics in World are directly collected from World Totals rather than the cross-sectional data aggregated by countries.
• Numbers in parentheses indicate the weighting of sample countries in each continent to World Totals.
• Weightings across four continents do not sum to one because of the sample selection.

and more than 248,000 people died as a result. By June, 50% of confirmed coronavirus cases in the world originated from America. In contrast, Africa had the lowest confirmed cases and deaths among the continents.

This paper uses the lockdown classification by the British Broadcasting Corporation. There are three categories of lockdown. These are identified as being, national, local and moderate. In Appendix 1, countries which have adopted the same lockdown category are grouped together for analysis using the stringency index. The stringency index represents the government response to take measures to control the pandemic and it is a composite measure based on nine response indicators. The nine metrics used to calculate the government stringency index consist of school closures, workplace closures, cancellation of public events, restrictions on public gatherings, closing public transport, stay-at-home requirements, public information campaigns, restrictions on internal movements, and international travel controls (Statistics and Research, Policy responses to the coronavirus pandemic, 2020). The index is rescaled to a value from zero to one hundred, one hundred being the strictest response. Hale et al. (2020) use the stringency risk ratio to identify the variation of responses to the pandemic by the government and demonstrate that there is significant variation in the risk control measures across different governments. It is our view that the pandemic has created a wide range of responses and control measures. Under the three lockdown categories, we find that on average, countries who have implemented a national lockdown have a higher stringency index than countries who have implemented a local or moderate lockdown. Many European countries have adopted a national lockdown. Flaxman et al. (2020) report eleven European countries that have imposed different combinations of control measures and large-scale lockdowns. In particular, Germany and the United Kingdom imposed restrictions such as national school closures and are of the same national lockdown group. Countries like Germany and Netherlands have exhibited a high stringency index of 73.15 and 79.63 respectively in March. According to the British Broadcasting Corporation, they are in the same national lockdown group. However, in March, Sweden had a stringency index of 35.19 and as a result, remained in the moderate lockdown group. Countries in Asia mostly adopted local and moderate lockdown measures. For instance, Singapore implemented social distancing measures in March and school closures and workplace distancing in early April (Dickens et al., 2020). The stringency index before March was below

Table 2
Classification of coronavirus lockdown by accumulated cases and new cases from March to June 2020.

			March		April		May		June	
			Total cases	New cases	Total cases	New cases	Total cases	New cases	Total cases	New cases
National lockdown	Asia	Mean1	72.94	6.36	176.60	2.88	320.25	6.92	621.24	10.54
		SD1	154.76	12.68	338.64	3.76	521.01	8.51	785.00	10.90
		Mean2	24.25	1.88	80.57	2.27	232.91	7.98	594.83	14.48
	Europe	Mean1	553.55	41.31	1633.97	22.20	2088.79	10.95	2452.13	11.96
		SD1	601.67	48.26	1361.21	18.80	1576.54	15.22	1698.40	11.90
		Mean2	633.99	46.65	1864.37	30.24	2733.55	22.67	3322.20	17.93
	America	Mean1	45.81	3.28	356.12	13.30	1015.48	42.81	2301.54	57.41
		SD1	68.95	5.28	549.36	24.11	1425.69	63.41	2745.67	67.81
		Mean2	28.66	2.40	340.63	16.76	1179.82	51.47	2590.03	61.71
	Africa	Mean1	13.14	1.40	47.47	1.27	168.76	4.40	428.26	11.79
		SD1	29.70	4.24	76.00	1.83	224.10	9.08	717.23	30.75
		Mean2	6.77	0.31	36.02	1.87	178.22	10.01	668.34	23.77
Local lockdown	Asia	Mean1	29.41	2.87	75.28	1.56	174.29	5.41	345.03	8.38
		SD1	52.09	5.45	80.37	2.32	182.38	9.30	399.71	13.78
		Mean2	43.39	0.79	55.21	0.39	77.33	1.19	115.34	1.51
	Europe	Mean1	342.49	13.81	841.76	17.27	1104.68	3.01	1310.69	8.47
		SD1	394.99	11.11	595.53	11.00	522.23	5.21	318.01	5.84
		Mean2	110.05	5.14	410.25	12.51	702.82	0.91	1091.35	12.87
	America	Mean1	134.82	17.22	918.61	29.56	2435.28	73.15	5080.77	76.40
		SD1	174.55	23.90	1077.57	27.47	2059.74	84.09	4959.96	75.89
		Mean2	281.31	36.64	1862.96	56.19	3868.06	96.94	6854.25	111.20
	Africa	Mean1	2.86	0.31	25.19	1.34	89.94	3.36	248.05	7.25
		SD1	3.31	0.54	26.62	2.19	89.34	5.02	268.51	14.72
		Mean2	1.66	0.23	15.45	1.04	57.03	2.02	138.98	2.63
Moderate lockdown	Asia	Mean1	87.11	0.69	482.14	22.39	1216.04	31.28	1578.82	7.70
		SD1	108.41	1.06	902.94	43.77	2152.04	56.42	2793.59	13.62
		Mean2	58.20	0.95	183.58	4.26	288.24	2.97	346.18	1.66
	Europe	Mean1	165.06	9.58	1035.63	45.57	2262.08	40.23	3565.14	71.17
		SD1	175.65	15.40	812.78	48.02	2077.73	46.42	3528.28	120.56
		Mean2	160.83	12.35	1193.34	55.15	2691.84	50.10	4332.48	91.62
	America	Mean1	28.80	2.62	113.81	3.69	306.47	6.46	635.75	7.76
		SD1	43.28	3.86	77.51	3.61	253.30	10.64	718.12	14.50
		Mean2	10.28	0.94	132.68	7.52	631.53	20.40	1580.77	26.83
	Africa	Mean1	2.72	0.30	52.69	2.44	290.66	25.78	529.97	9.79
		SD1	3.17	0.52	76.64	5.60	447.14	61.10	840.77	27.51
		Mean2	1.86	0.41	23.69	0.85	102.81	6.55	199.61	2.05

Mean1 is the sum of total confirmed cases per million or new cases per million in each country divided by the number of countries in each continent. SD1 is the standard deviation of total confirmed cases per million or new cases per million across countries in each continent. For example, in March, the mean and standard deviation of total confirmed cases per million for countries in America imposing a local lockdown was 134.82 and 174.55 respectively. These countries in America consist of Brazil (21.54), Canada (196.70), Chile (128.11), Cuba (15.01), Dominican Republic (83.06), Guatemala (2.01) and the United States (497.34). New cases are based on the new confirmed cases per million at the end of each month. New cases per million at the end of March for countries in America that imposed a local lockdown was Brazil (1.52), Canada (30.97), Chile (16.22), Cuba (2.74), Dominican Republic (3.87), Guatemala (0) and the United States (65.24). On the other hand, Mean2 is the sum of total confirmed cases or new cases divided by the sum of population per million for countries in each continent. Total cases in March for countries in America imposing a local lockdown were Brazil (4579), Canada (7424), Chile (2449), Cuba (170), Dominican Republic (901), Guatemala (36) and the United States (164620). New cases at the end of March for countries in America that imposed a local lockdown were Brazil (323), Canada (1169), Chile (310), Cuba (31), Dominican Republic (42), Guatemala (0) and the United States (21595). The total population in America that imposed a local lockdown was 640510509.

forty and as a result, Singapore is categorised as having implemented a moderate lockdown. In contrast, China which adopted a local lockdown in March had a high stringency index of 81. Therefore, this paper reassesses the three categories of lockdown against the stringency index analysed by the Oxford Martin School.

Table 2 focuses on the different categories of lockdown across four regions. The data is compared and collected between the period, March and June 2020 showing the number of new cases and confirmed cases per million. European countries that imposed a national lockdown saw on average, 553.55 and 633.99 of total confirmed cases per million in March 2020. This number was higher than any other region. The growth of new cases appeared to increase at a much faster rate in America than other continents. What is interesting, is that there were very few confirmed cases reported in March in Africa. This tells us that there is a cross-continental difference between the continents.

Figures 1 and 2 provide an outlook on the international growth trend of daily new confirmed cases following the outbreak in January this year. These figures show that the virus reached the peak in April and appeared to slow thereafter with an average daily value of one million cases. This continued until June when cases started to increase again.

Figures 3 to 10 provide a breakdown on coronavirus cases in four regions between April and June 2020. Europe exhibits a downward trend during this period. However, in Asia, Africa and America, the virus exhibits an upward trend. In America, the daily number of cases in April was approximately 40,000. The number of new cases increased gradually in May, and then rapidly in June taking the highest daily number of cases to above 100,000.

3.2. Research methodology

This paper uses the regression analysis and logistic growth curves to evaluate how effective lockdown is against the spread of the virus.

Table 3 focuses on the key variables that relate to the number of confirmed cases. There exists a correlation matrix between the variables. The variables are used in the regression model to show the descriptive statistics and correlation matrix. On average, the number of daily new cases in the world has increased to 463 per million per day. On a global scale, Asia and Africa have the lowest confirmed number of new cases to date. In contrast, America has recorded the highest number of daily new cases, taking first place with 921 new cases per million. Europe is in second place with 665 per million cases per day. Africa has a low median. Europe and America appear to have high medians thereby indicating that those with high medians carry within their respective countries, a higher infection rate. Over the sample period, Europe has a lower standard deviation than America indicating that the virus spreads more widely there. Accordingly, this table finds that there is a positive relationship between countries implementing a national lockdown and daily new cases, and a positive relationship between national lockdown and GDP per capita.

3.2.1. Cross-sectional regression equations

The dependent variable is the increase in new confirmed cases per million in a country. Data is collected over a period of three months. Countries with a population of less than one million have been excluded in the regression sample as the population size is too small to clearly identify the variables applicable during the sample period. It is commonly recognised that there are many healthy factors affecting the infection rate of the virus (Ferrar et al, 2020; Harapan et al., 2020; Holman et al., 2020; Petrilli et al., 2020; Zhang et al., 2020). Hence this paper focuses on six variables, the three categories of lockdown, total confirmed cases per million, underlying health conditions, hospital beds, GDP per capita, and population. We include the total number of confirmed cases per million in the regression equations as we assume that the current level of accumulated confirmed cases in a population will affect the growth of new coronavirus cases. Recent studies (Gros et al., 2020; Liu et al. 2020; Mellan et al. 2020; Zhang et al., 2020) show that the coronavirus has a high reproduction number compared to SARS. The coefficient of total cases can be regarded as the reproduction rate which in turn indicates the speed in which the virus spreads.

The general form of cross-sectional regression equations describes the relationship between an increase in new confirmed cases and a set of explanatory variables as

$$y_i = \beta_0 + \beta_1 \boldsymbol{National}_{i1} + \beta_2 \boldsymbol{Local}_{i2} + \beta_3 \boldsymbol{Total\ cases}_{i3} + \beta_4 \boldsymbol{GDP}_{i4} + \beta_5 \boldsymbol{Population}_{i5} + \beta_6 \boldsymbol{Underlying}_{i6} + \beta_7 \boldsymbol{Bed}_{i7} + e_i \quad (1)$$

where y_i is the dependent variable indicating the increase in the new confirmed cases per million in a month. The increase in new confirmed cases per million in a month is calculated using the accumulated confirmed cases at the end of the month subtracted by the accumulated confirmed cases at the end of the previous month. The subscript i indexes countries. β_0 is the constant term, and β_1, $\beta_2 \ldots \beta_7$ are the regression coefficients corresponding to the set of explanatory variables in Eq. (1). e_i is the error term. In Eq. (1) we include k-1 dummy variables, where k stands for the total number of various lockdowns imposed in a country. These can be categorised as national, local, and moderate lockdown. The category that is left out of the regression equation is defined as the base category. Many econometric textbooks (see Greene, Chapter 11, 2012) have included dummy variables in the estimated equation. Both GDP and population take the natural log of GDP per capita and population in each month.

To provide a more comprehensive examination of the relationship between various levels of lockdown and increase in new cases, two specific methodologies are conducted. First, GDP per capita, population, underlying health conditions and hospital beds are taken as time invariant over the period. Since many explanatory variables do not change over time, we have pooled data across the countries and have specified a model with dummy variables with respect to national and local lockdown. This allows the slope coefficients to vary between different types of lockdown restrictions.

$$y_i = \beta_0 + \beta_1 \boldsymbol{National}_{i1} + \beta_2 \boldsymbol{Local}_{i2} + \beta_3 \boldsymbol{Total\ cases}_{i3} + e_i \quad (2)$$

In Eq. (2), the moderate lockdown is the base group as this is the group designated when national and local variables have the value zero.

To examine the regional differences of those affected by the pandemic, we specify separate regional dummy variables in Asia, Europe, and America and take into account the interaction effect between each continent and lockdown in the regression. The equation is expressed as

$$y_i = \beta_0 + \beta_1 \boldsymbol{Asia}_{i1} + \beta_2 \boldsymbol{Europe}_{i2} + \beta_3 \boldsymbol{America}_{i3} + \beta_4 \boldsymbol{Population}_{i4} + \beta_j X_m X_n + e_i \quad (3)$$

where y_i is the dependent variable indicating the increase in the confirmed cases per million in a month. The subscript i indexes regions, β_0 is the constant term, and β_1, $\beta_2 \ldots \beta_j$ are the regression coefficients corresponding to the set of explanatory variables. $X_m X_n$ refers to the interaction effect X_m and X_n which capture the interactions between a continent and a particular type of lockdown. The natural log of population measures the spread of the virus on a population size.

Second, our models include dummy variables because we wish to explore the lockdown effect on reducing the growth of the virus. The assumption of differing intercepts for different type of lockdown can be tested using the F-test statistic:

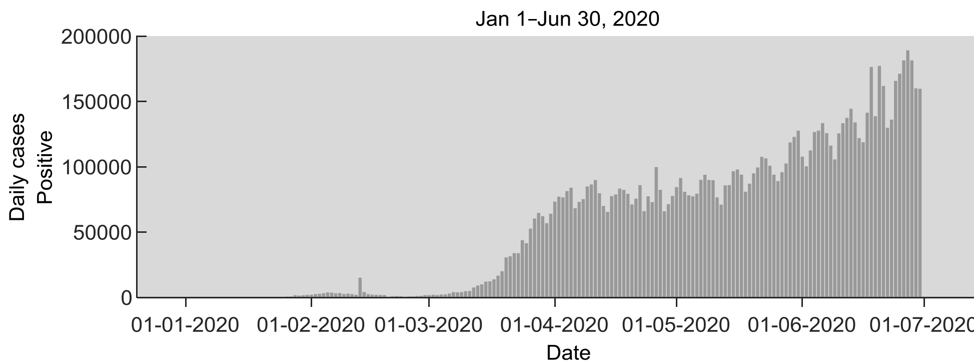

Fig. 1. Global new cases January 1-June 30, 2020.

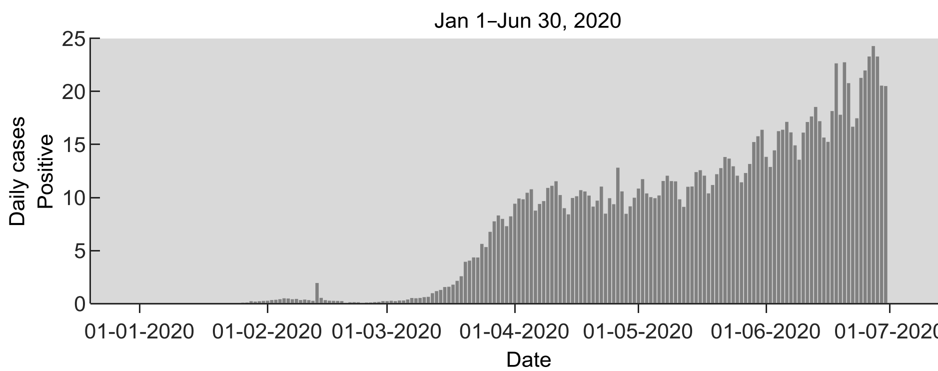

Fig. 2. Global new cases per million January 1-June 30, 2020.

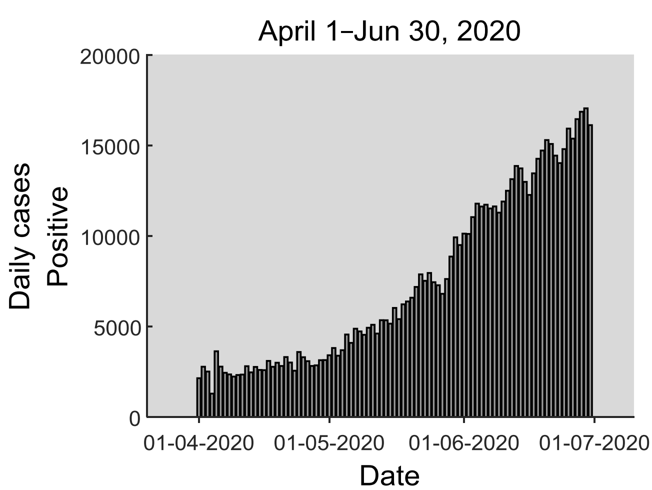

Fig. 3. New cases in Asia April 1-June 30, 2020.

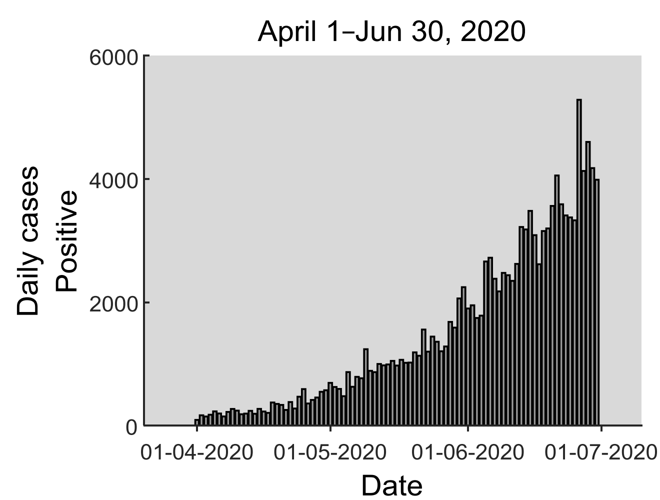

Fig. 4. New cases in Africa April 1-June 30, 2020.

$$F = \frac{(SSE_R - SSE_U)/J}{SSE_U/(NT - K)}$$

where SSE_R is the restricted sum of squared errors. SSE_U is the unrestricted sum of squared errors, J is the number of joint hypotheses, and NT-K is the number of degrees of freedom in the unrestricted model (Greene, 2012). If a large F-statistic indicates that the null hypothesis is not true, this implies that imposing a lockdown can reduce the virus growth.

Many European countries went into a national lockdown in March with measures gradually easing in May and June (Cresswell et al., 2020; Flaxman et al., 2020; Meunier, 2020). This paper further explores the timing in which lockdown was imposed and lifted across countries by carrying out logistic regression. Our sample of countries are divided into two groups, those that have implemented a national lockdown and those that have not. Thus, the dependent variable $y_i = 1$ if a national lockdown is chosen.

The general form of estimating the logistic regression model is

$$y_i = ln\left(\frac{p(\mathrm{x})}{1 - p(\mathrm{x})}\right) = \beta_0 + \beta_1 D_{i1} + \beta_2 D_{i2} + \beta_k x_{ik} + e_i \tag{4}$$

Table 3
Descriptive Statistics and Correlation Matrix.

	New cases	National	Local	Moderate	Total cases	GDP	Population	Underlying1	Underlying2	Bed
Mean	463.74	0.50	0.32	0.18	1045.65	9.21	16.71	246.66	6.64	2.87
Median	112.46	0.00	0.00	0.00	266.18	9.41	16.66	232.35	6.35	2.10
SD	906.23	0.50	0.47	0.39	1730.19	1.24	1.43	121.28	3.24	2.74
Africa										
Mean	112.99	0.27	0.48	0.24	171.15	7.85	16.65	281.61	4.99	0.87
Median	36.43	0.00	0.00	0.00	51.48	7.61	16.73	269.05	3.94	0.50
SD	266.52	0.45	0.50	0.43	381.00	0.94	1.20	74.41	4.22	1.25
America										
Mean	921.86	0.54	0.29	0.17	1541.91	9.43	16.58	179.82	8.38	1.91
Median	351.47	1.00	0.00	0.00	451.18	9.52	16.26	164.00	8.24	1.60
SD	1504.39	0.50	0.46	0.38	2498.36	0.74	1.32	68.04	1.98	1.19
Asia										
Mean	220.84	0.36	0.44	0.20	466.92	9.37	17.57	281.00	7.79	3.19
Median	46.13	0.00	0.00	0.00	131.99	9.36	17.48	260.94	7.26	2.10
SD	514.13	0.48	0.50	0.40	1157.47	0.98	1.72	164.50	2.99	3.37
Europe										
Mean	665.33	0.79	0.09	0.12	1997.68	10.27	16.19	234.29	6.17	5.31
Median	327.30	1.00	0.00	0.00	1497.88	10.31	16.06	175.70	5.76	5.57
SD	779.60	0.41	0.29	0.33	1644.28	0.56	1.18	129.36	1.82	2.10
Full sample										
	New cases	National	Local	Moderate	Total cases	GDP	Population	Underlying1	Underlying2	Bed
New cases		0.0549	-0.0433	-0.0186	0.8335	0.3039	0.0437	-0.1980	0.0865	0.0963
National			-0.6828	-0.4686	0.1550	0.2987	-0.0567	-0.0734	0.1921	0.1221
Local				-0.3255	-0.1241	-0.2793	0.1976	0.1224	-0.1972	-0.2282
Moderate					-0.0504	-0.0490	-0.1655	-0.0530	-0.0102	0.1179
Total cases						0.4601	0.0227	-0.3061	0.0560	0.1790
GDP							-0.0754	-0.4494	0.2726	0.5672
Population								0.0070	0.0323	-0.0859
Underlying1									0.0488	0.0497
Underlying2										0.0859
Bed										

New cases are new cases per million. The types of lockdown are separated into three categories: national, local, and moderate lockdown. Total cases represent the total confirmed cases per million. GDP is the log of per capita GDP. Population is the log of population in a country. Underlying1 is cardiovascular disease. Underlying2 is diabetes. Bed is the number of hospital beds available for every 1000 inhabitants in a population.

where p is the conditional probability that the outcome is present, vector $x' = (D_1, D_2, x_k)$ and the subscript i indexes countries. D1 is a dummy variable which is based on the difference in new cases over the lockdown period from April to May. D1 = 1 if new cases between May and April are expected to decrease, D1=0 if otherwise. D2 is a dummy variable which is based on the difference in new cases after the lockdown period between June and May. D2 = 1 if new cases after the lockdown period is expected to decrease, D2=0 if otherwise. x_{ik} are regional dummy variables in Asia, Europe, and America.

D1 is used to test the lockdown decision on imposing national lockdown restrictions between April and May 2020. If the D1 coefficient is positive, this will indicate that national lockdown leads to a reduction in virus cases over the period April and May 2020. D2 is to test the post-lockdown effect after the lockdown period May to June. If the D2 coefficient is positive, this will indicate that lifting national lockdown has led to a reduction in virus cases over the period May and June 2020. We therefore assume that new cases are likely to reduce during the lockdown period between April and May 2020 but increase after the lockdown period ends between May and June 2020. Thus, we expect D1 to be positive and D2 to be negative.

3.2.2. *Logistic growth model*

The logistic growth curve has been a useful and valid model to model new technology adoption and growth patterns. Recently there have been a number of studies applying the S-curve to examine the outbreak of Covid-19 infections (Postnikov, 2020; Wu et al., 2020). Postnikov (2020) utilises the logistic specification of Meyer et al. (1999) with the Fisher-Pry plot (Fisher and Pry, 1971) to investigate the predictability of the S-curve across countries to show that the logistic model adequately reproduces the epidemic dynamics. In turn, Wu et al. (2020) collect data in China to conclude that logistic models provide an accurate short-term prediction but tend to underestimate the final confirmed cases in the long term. To date, there are few studies incorporating the logistic model to look into the effect of lockdown. As a result, this paper undertakes the simple logistic growth model and bi-logistic growth model (Meyer, 1994; Meyer et al., 1999) to examine the effectiveness of national lockdown in European countries.

The simple logistic and bi-logistic growth models are

$$N(t) = \frac{\mathrm{A}}{1 + \exp(-\mathrm{k}(\mathrm{t} - \mathrm{t}_m))} \tag{5}$$

$$N(t) = \frac{\mathrm{A}_1}{1 + \exp(-\mathrm{k}_1(\mathrm{t} - \mathrm{t}_{m1}))} + \frac{\mathrm{A}_2 - A_1}{1 + \exp(-\mathrm{k}_2(\mathrm{t} - \mathrm{t}_{m2}))} \tag{6}$$

where $N(t)$ is denoted as total confirmed cases at time t; A, A_1, A_2 are the carrying capacity of growth curves; k, k_1, k_2 are the proportionality constant of growth curves that determine the rate of growth and decay; t_m, t_{m1}, t_{m2} are the midpoint of the growth trajectories.

4. Estimation results

4.1. *Regression results*

Model 1 in Table 4 analyses moderate lockdown as the base group and examines the effect of different categories of lockdown on the growth of new cases per million each month. There are two main findings in Model 1. First, we find that national lockdown and local lockdown result in the reduction in coronavirus cases in May. This is being

Table 4
Regression results describing the relationship between a set of variables and new confirmed cases.

	April Model 1	April Model 2	April Model3	May Model 1	May Model 2	May Model 3	June Model 1	June Model 2	June Model 3
Constant	111.3663	-439.2743	-181.4820	361.0212	-596.4322	115.3733	359.9951	499.9567	1246.7866
	(1.9620)**	(-1.0381)	(-0.4693)	(3.1153)***	(-0.8833)	(0.1715)	(2.7254)***	(0.6963)	(1.7824)*
National	-108.7722	-158.3120	-141.9815	-430.5130	-437.6400	-378.8806	-272.9224	-174.4171	-75.2747
	(-1.6319)	(-1.8686)*	(-1.7565)*	(-3.0170)***	(-3.1537)***	(-2.8983)***	(-1.8038)*	(-1.0446)	(-0.4212)
Local	-60.5463	-113.8382	-87.2087	-233.6721	-277.1746	-177.8718	-186.9979	-208.9617	-62.0743
	(-0.9255)	(-1.3942)	(-1.1358)	(-1.7664)*	(-2.0849)**	(-1.4280)	(-1.3672)	(-1.3619)	(-0.3586)
Total cases	0.6599	0.6559	0.6559	0.3418	0.3631	0.3680	0.2215	0.2847	0.2903
	(14.1300)***	(12.5369)***	(12.1659)***	(6.8476)***	(6.1950)***	(6.1658)***	(5.6786)***	(6.4730)***	(6.7938)***
GDP		38.3952	8.6191		-21.5096	-107.5300		-101.1151	-198.1837
		(0.9785)	(0.2568)		(-0.3263)	(-1.7914)*		(-1.5458)	(-3.6650)***
Population		12.1569	12.2788		55.2723	49.7267		27.2661	18.3083
		(0.7504)	(0.7495)		(1.6584)*	(1.4691)		(0.8116)	(0.5932)
Underlying1		0.2823			0.8187			0.8514	
		(1.5134)			(2.0330)**			(1.9075)*	
Underlying2			6.4948			31.3974			45.0161
			(0.8848)			(2.3674)**			(2.3807)**
Bed		-10.9582	-1.9662		1.3028	35.3496		-13.0611	22.9852
		(-0.9589)	(-0.1786)		(0.0448)	(1.2513)		(-0.4953)	(1.0050)
Adjusted R2	0.9145	0.9119	0.9111	0.6204	0.6573	0.6580	0.4513	0.5316	0.5447
F statistic	189.9438***	151.9509***	148.2098***	95.0259***	88.7817***	86.7646***	28.2123***	43.9819***	46.0967***
F 1% critical value	2.1212	2.4358	2.4358	2.1212	2.3405	2.3405	2.1499	2.4008	2.4008
Observations	87	73	73	87	79	79	85	76	76

This table shows the effect of lockdown on new confirmed cases in Model 1, and key factors affecting the new confirmed cases in Models 2 and 3. The dependent variable is the increase in new confirmed cases in April, May, and June respectively. Standard errors are first estimated by ordinary least squares and then calculated by using White's heteroskedasticity-consistent estimator. The F statistic is based on the Goldfeld-Quandt test for heteroskedasticity and we conduct a heteroskedastic partition for the confirmed cases variable. t-statistics are in parenthesis. ***,** and * indicate significance 1%, 5% and 10% levels respectively.

Table 5
The increase in new cases per month due to countries imposing national lockdown.

Country	April	May	June	change	Country	April	May	June	change
Bangladesh	42.83	227.73	590.16	+ +	Serbia	1173.18	390.47	427.21	− +
India	23.04	108.04	278.77	+ +	Slovakia	193.24	23.81	26.38	− +
Iran	621.03	658.31	907.87	+ +	Slovenia	315.07	26.46	53.87	− +
Malaysia	102.55	56.14	27.03	− −	Spain	2372.29	518.58	210.50	− −
Nepal	1.78	46.13	406.60	+ +	Switzerland	1607.47	166.15	93.25	− −
New Zealand	99.95	5.18	4.98	− −	United Kingdom	2107.65	1585.08	576.54	− −
Pakistan	63.99	243.27	633.07	+ +	Argentina	73.15	263.94	1018.99	+ +
Sri Lanka	24.70	45.35	19.71	+ −	Bolivia	85.93	726.63	1930.35	+ +
Uzbekistan	55.36	46.37	141.74	− +	Colombia	106.38	432.86	1312.96	+ +
Albania	188.69	123.71	467.02	− +	Costa Rica	75.18	65.57	436.19	− +
Austria	637.99	141.46	114.14	− −	Ecuador	1287.14	787.62	968.88	− +
Belgium	2971.63	763.70	244.62	− −	El Salvador	53.19	329.93	563.66	+ +
Bulgaria	156.58	153.42	333.60	− +	Haiti	5.35	156.90	356.76	+ +
Croatia	309.85	44.82	116.68	− +	Honduras	63.61	436.46	1385.62	+ +
Czech Republic	427.40	154.17	240.45	− +	Panama	1229.04	1538.90	4581.24	+ +
Denmark	1110.29	453.20	193.02	− −	Paraguay	25.80	100.25	172.03	+ +
Estonia	716.90	150.01	91.97	− −	Peru	1000.28	3692.24	3842.49	+ +
France	1285.24	353.19	195.55	− −	Trinidad and Tobago	22.15	0.72	6.43	− +
Germany	1160.20	266.91	152.50	− −	Venezuela	6.89	39.67	143.16	+ +
Greece	130.86	32.52	45.57	− +	Angola	0.61	1.73	5.84	+ +
Ireland	3512.30	946.98	107.94	− −	Congo	36.43	66.51	119.24	+ +
Italy	1684.57	480.85	128.54	− −	Egypt	45.53	177.66	423.17	+ +
Lithuania	327.30	108.37	53.63	− −	Kenya	6.21	27.97	80.01	+ +
Moldova	860.94	1072.64	2047.37	+ +	Mauritius	160.41	2.36	4.72	+ +
Netherlands	1578.77	435.08	231.46	− −	Rwanda	11.97	10.35	49.57	− +
Poland	279.68	288.82	279.63	+ −	South Africa	67.85	431.93	1910.29	+ +
Portugal	1793.13	736.61	952.17	− +	Uganda	1.05	7.26	9.99	+ +
Romania	521.16	371.93	387.21	− +	Zimbabwe	1.82	9.42	26.91	+ +
Russia	668.54	2036.37	1675.97	+ −					

April, May, and June indicate an increase in new confirmed cases per million. This is compared to an increase in new cases in the previous month. The minus sign indicates a reduction in new confirmed cases in the month compared to the previous month, and the positive sign indicates an increase in new confirmed cases in a given month compared to the previous month.

significant at the 1% and 5% respectively in comparison with countries which have imposed a moderate lockdown. The significant coefficients in regression 1 suggest that the implementing lockdown in March has gradually reduced the virus growth in May. The regression coefficient of lockdown in May is the lowest compared to the months in April and June in regression model 1. This indicates that the virus growth is lower in May than in April and June when countries imposed a national lockdown. Second, we find that the variable of Total Cases is a positive and statistically significant at the 1% level. This indicates the significant effect of the reproduction rate on new cases. In addition, we find the R number is at 0.66 in April before most countries eased national lockdown measures in May and June. This finding of the R number implies that implementing lockdown has led to a reduction in the rate of infection.

Regressions 2 and 3 examine key factors relating to the increase in new cases. We find the GDP negative and statistically significant at the 10% level in May. This implies that countries with high incomes are likely to implement strong lockdown measures and have slower infection rates in the number of new cases recorded. We investigate the risk of having an underlying health condition with the risk of infection. We find evidence that there is a positive and statistically significant relationship between those with underlying health conditions and the increase in new cases. This indicates that those with underlying health conditions are in a high risk-group and are more likely to be infected by the coronavirus. In terms of a country's population and medical resources, our findings show that the virus spreads regardless of this.

It should be noted that we have conducted the Goldfeld-Quandt test to test for homoscedasticity in each regression equation and each regression sample is partitioned into two subsamples. We assume that variance tends to increase with the number of confirmed cases and thus our observations in each regression model have been made according to the total number of confirmed cases per million in a population, and using a partition of half observations in each subset of the observations. The test statistic of Goldfeld-Quandt is based on the F-distribution

$$F = \frac{SSR_2/df_2}{SSR_1/df_1}$$

where SSR_1 is the sum of squared residuals for the small variance group; SSR_2 is the sum of squared residuals for the large variance group; df_1 and df_2 are the degree of freedom for small and large groups respectively.

According to the Goldfeld-Quandt test, we conclude that the null hypothesis of homoskedasticity is rejected and there is heteroskedasticity in the error variance. The standard errors for the least squares estimators may be incorrect. The estimated results of standard errors in our regressions are calculated by using White's heteroskedasticity-consistent estimator that allows for the possibility of heteroskedasticity.

Table 5 shows the increase in new cases between April and June for countries which introduced a national lockdown. Since the lockdown in March, there have been a reduction of new cases as seen by the negative sign. The number of new cases recorded in May suggests that national lockdown is effective in preventing the virus spread. In contrast, we see a positive sign in June which indicates that the number of new cases increased post-lockdown in this month. Many European countries such as Demark, France, Germany, and the United Kingdom have had fewer new cases recorded during lockdown in April and post-lockdown in June. However, the number of new cases increased in June in other countries such as Serbia, Slovenia, Costa Rica, and Ecuador. It should be noted that national lockdown did not provide the same level of reduction in new cases in Bangladesh, Moldova, and Egypt which suggests that other measures along with implementing national lockdown need to be taken into consideration to have positive results.

Table 6 shows the increase in the number of new cases per month for countries imposing local lockdown. The sample countries which implemented a local lockdown in April, May, and June had average values of 221.45, 367.43, and 640.61 respectively. However, in table 5 for the same months of April, May and June, the average values in the sample countries that implemented a national lockdown were 587.58, 395.94, and 557.99 respectively. Tables 5 and 6 show us two characteristics between national lockdown and local lockdown that are significant. First, countries that imposed a national lockdown in April tended to have a higher number of confirmed cases per million than countries which imposed a local lockdown. Second, countries which imposed a local lockdown have a low number of confirmed cases in April which rapidly increased in May and June. This indicates that local lockdown may not be an effective way to control the virus.

Table 7 assesses how the virus affects different regions in Asia, Europe, America, and Africa. We create three dummy variables and take Africa as the base group in the regression models. In addition, we also consider the interaction effect between each continent and whether they implemented a national lockdown or local lockdown in the regression. The regression analysis of Region 1 and Region 2 shows that Europe and America have a higher number of confirmed cases per million than Africa. This is being significant at the 1% level over the period between April and June 2020. For example, if we hold the effect of a population as constant in the Region 2 regression, Europe has a higher number of confirmed cases of 587.6301 per million than Africa.

The interaction effect in the Europe equation is estimated by the coefficient of Europe plus the coefficient, Europe*National which is 551.3438. The Europe equation consists of countries in Europe which imposed a national lockdown. This indicates that European countries which implemented a national lockdown have a higher number of confirmed cases than Africa. However, the number is 246.2428 for countries in Europe which imposed a local lockdown. Our findings show that on average, countries in Europe and America tend to have a higher number of confirmed cases than Africa and Asia. This finding is consistent with the data shown in Table 3. Second, countries in America which have imposed a local lockdown tend to have higher confirmed cases than those which have imposed a national lockdown. This is the opposite to countries in Europe. The regression results are consistent with the results in Table 2.

We have observed that many European nations have imposed a national lockdown in March. It is widely debated which form of lockdown is most effective. This paper has examined the validity of the national lockdown decision by applying the binary logistic regression models and the dependent variable which is dichotomised into countries which have imposed either a national lockdown or no national lockdown.

Table 8 shows the logistic regression coefficient, standard error of each estimate, Wald test, p-value, and odds ratio[4] for each of the predictors. Model 1 in Table 8 investigates whether imposing national lockdown in March decreased the rate of infection between April and May 2020, and whether the decision to ease national lockdown led to an increase in new cases between May and June 2020. The virus reduction is defined as the difference between new cases per million in May and in April. We assign D1=1 if there is a reduction in new cases and D1 = 0 if not. Similarly, the virus reduction is defined as the difference between new cases per million in June and in May. D2 = 1 if there is a reduction in new cases and D2 = 0 if not. The results taken from Model 1 show that implementing a national lockdown has resulted in a reduction in cases between April and May 2020. However, easing national lockdown in May has resulted in an increase in new cases between May and June 2020.

Model 1 supports the effectiveness of imposing a national lockdown in March 2020. This finding is consistent with the recommendation by Melnick and Ioannidis (2020) and Zhang et al. (2020) suggesting that Covid-19 is more infectious than any other coronaviruses such as SARS.

[4] The odds ratio for a dichotomous independent variable is the ratio of the odds for a value of 1 to the odds for a value of 0. The relationship between the odds ratio and the regression coefficient (β) is e^{β}.

Table 6
The increase in new cases per month due to countries imposing a local lockdown.

Country	April	May	June	change	Country	April	May	June	change
Afghanistan	46.44	323.06	429.33	+ +	Guatemala	30.64	231.87	707.21	+ +
Australia	85.84	17.22	22.82	− +	United States	2644.36	2206.86	2477.83	− +
China	1.18	0.13	0.45	− +	Benin	5.20	13.45	78.77	+ +
Indonesia	30.55	58.50	107.19	+ +	Burkina Faso	20.05	10.14	5.07	− −
Kazakhstan	153.38	407.58	583.76	+ +	Central African Republic	9.11	188.83	548.89	+ +
Kyrgyzstan	101.47	153.58	543.82	+ +	Cote d'Ivoire	40.56	59.18	243.19	+ +
Mongolia	7.93	43.01	12.51	+ −	Democratic Republic of Congo	4.49	27.53	44.36	+ +
Myanmar	2.50	1.36	1.38	− +	Ethiopia	0.93	8.12	41.61	+ +
Philippines	55.92	82.24	175.34	+ +	Ghana	48.89	196.22	308.40	+ +
Thailand	18.67	1.82	1.29	− −	Guinea	101.65	179.32	125.26	+ −
Vietnam	0.66	0.59	0.29	− −	Liberia	27.29	27.48	96.88	+ +
Finland	648.47	346.53	69.13	− −	Mali	22.91	37.93	45.58	+ +
Norway	634.73	137.24	81.90	− −	Mauritania	0.43	102.37	788.44	+ +
Ukraine	214.62	304.98	467.01	+ +	Namibia	1.97	2.76	68.09	+ +
Brazil	346.18	1977.23	4091.82	+ +	Niger	28.63	10.04	4.92	− −
Canada	1170.12	1022.52	363.73	− −	Nigeria	7.75	39.42	74.12	+ +
Chile	650.55	4183.52	9475.78	+ +	Senegal	43.00	158.45	188.91	+ +
Cuba	114.51	49.26	27.81	− −	Togo	9.06	39.14	25.37	+ −
Dominican Republic	530.15	945.44	1374.28	+ +					

April, May, and June indicate an increase in new confirmed cases per million. This is compared to an increase in new cases in the previous month. The minus sign indicates a reduction in new confirmed cases in the given month compared to the previous month. The positive sign indicates an increase in new confirmed cases in the month compared to the previous month.

Table 7
Regional differences on the spread of the virus.

	Region 1	Region 2	Asia	Europe	America
Constant	112.9884 (4.2396)***	-1167.6362 (-2.3033)**	-1366.0210 (-2.8536)***	-1259.5198 (-2.4615)**	-669.3978 (-1.4102)
Asia	107.8526 (1.6666)*	37.0941 (0.4492)	407.2314 (1.4803)	32.0172 (0.3851)	64.6233 (0.8049)
Europe	552.3436 (6.7043)***	587.6301 (7.0351)***	593.0964 (7.1002)***	1100.4129 (3.4877)***	573.9016 (6.8849)***
America	808.8719 (4.5425)***	814.1688 (4.6349)***	814.9894 (4.6478)***	814.5489 (4.6411)***	115.9278 (1.5001)
Population		76.9058 (2.5358)**	88.8195 (3.1041)***	82.4237 (2.6927)***	46.9849 (1.6542)*
Asia*National			-431.9909 (-1.5661)		
Asia*Local			-512.6864 (-1.8618)*		
Europe*National				-549.0681 (-1.7018)*	
Europe*Local				-854.1701 (-2.6572)***	
America*National					540.9697 (2.9136)***
America*Local					1382.2456 (2.8768)***
F statistic	63.0795***	65.9082***	68.0825***	32.9453***	48.1111***

The dependent variable is the increase in the number of new cases in a month. Region 1 and Region 2 regressions are based on a dummy coding for each continent which is absent of an interaction effect between each continent and lockdown implementation. Each of the Asia (Europe or America) regression is the regression equation that considers the interaction effect between countries in Asia (Europe or America) imposing a national or local lockdown. t-statistics are in parenthesis. ***,** and * indicate significance 1%, 5% and 10% levels respectively.

The enforcement of lockdown is likely to reduce infections and it is the efficient way to stop the spread of the virus before a vaccine is made available. In Model 2, we focus on the lockdown decision made in each continent by adding three continent dummy variables with Africa that is treated as the base group. The results show that Europe is more likely to impose a national lockdown than other continents. Model 3 is used to compare a national lockdown decision across continents. The odds ratio indicates that when holding all other variables constant, Europe is three times more likely to adopt a national lockdown than in America. Similarly, Europe is six times more likely to adopt a national lockdown than Asia.

4.2. The nonlinear logistic model

Referring back to Figures 5 and 9, these figures show a gradual decline in the trend of daily new cases in Europe. We further utilise the logistic growth models by Meyer (1994) and Meyer et al. (1999) to investigate the growth trajectory of European countries which have imposed a national lockdown in March. In contrast to the findings by Meunier (2020), this paper shows that in Europe, countries which implemented a national lockdown effectively reduced the spread of the virus. This paper provides graphical outcomes to explain and strengthen the national lockdown decision in Europe.

The logistic growth curves shown in Figs. 11 and 13 are based on the accumulated confirmed cases. Figs. 12 and 14 are based on the daily confirmed cases. The cases increased slowly in January and February

Table 8
Logistic regression analysis on lockdown decisions.

	Variable	Estimate	SE	Wald's χ^2	p-value	Exp(β)
Model 1						
	Constant	-0.2442	0.2653	0.8473	0.3573	0.7833
	D1	1.3351	0.4631	8.3125	0.0039	3.8005
	D2	-0.9832	0.4785	4.2212	0.0399	0.3741
Model 2						
	Constant	-0.8088	0.4062	3.9646	0.0465	0.4454
	D1	0.5782	0.5382	1.1539	0.2827	1.7828
	D2	-1.5513	0.5991	6.7044	0.0096	0.2120
	Continent					
	Asia	0.5173	0.6175	0.7018	0.4022	1.6775
	Europe	2.7525	0.7442	13.6804	0.0002	15.6813
	America	1.0437	0.5874	3.1572	0.0756	2.8398
Model 3						
	Constant	-0.9808	0.3909	6.2969	0.0121	0.3750
	Continent					
	Asia	0.4055	0.5713	0.5037	0.4779	1.5000
	Europe	2.2930	0.5780	15.7377	0.0001	9.9048
	America	1.1479	0.5662	4.1098	0.0426	3.1515

SE is the standard error of the estimate and β is the regression coefficient. Exp(β) is the odds ratio. The Wald Chi-square statistic $=(\beta/SE)^2$. Model 1 has an overall percentage correct of 60.9, -2 log likelihood of 149.3 and the AIC of 155.3. Model 2 has an overall percentage correct of 69.6, -2 log likelihood of 130.5 and the AIC of 142.5. Model 3 has an overall percentage correct of 68.7, -2 log likelihood of 138.6 and the AIC of 146.6. The log of the likelihood is to measure how well the regression model fits the data. We also exclude the intercept in the model to a collinearity problem and the results of the lockdown decision in Europe do not change.

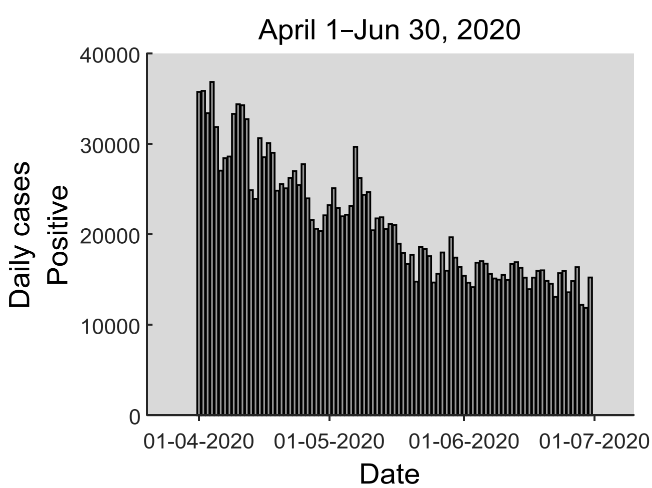

Fig. 5. New cases in Europe April 1-June 30, 2020.

2020. It should be noted that France reported its first three confirmed cases on the 25th January 2020. The number of daily confirmed cases began to accelerate significantly by the second half of March 2020. The data in this figure shows that the peak in new confirmed cases was reached by the end of March and early April. However, the number of daily confirmed cases began to increase again at the end of April and early May 2020. It appears that there was a moderate increase in the number of new cases over that period. However, the number of newly confirmed cases each day continued to fall after the peak in April. The growth pattern in the figures is complex and shows that the incidence of coronaviruses reaches a limit, but the growth is rejuvenated in another period of time. The double logistic captures a sudden and usual temporary growth of activity at the initial stage. In the second stage, a moderate upward growth spurt trajectory is seen.

Second, we look at the estimated logistic growth curves. Figs. 11 to 12 relate to the simple logistic model and show the growth curve of accumulated confirmed cases and daily growth rates of new cases. In contrast, Figs. 13 to 14 are based on the double logistic model. The results are summarised in the simple and double logistic curves displayed in Table 9. Evidently, the simple logistic model based on Figs. 11 to 12 has one point of inflection and one maximum growth rate. The inflection

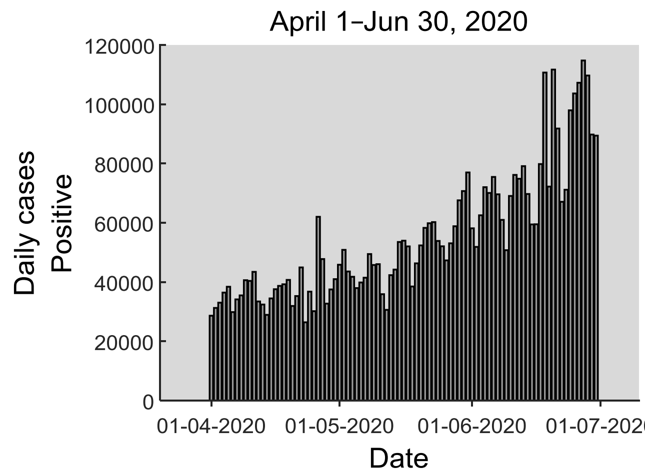

Fig. 6. New cases in America April 1-June 30, 2020.

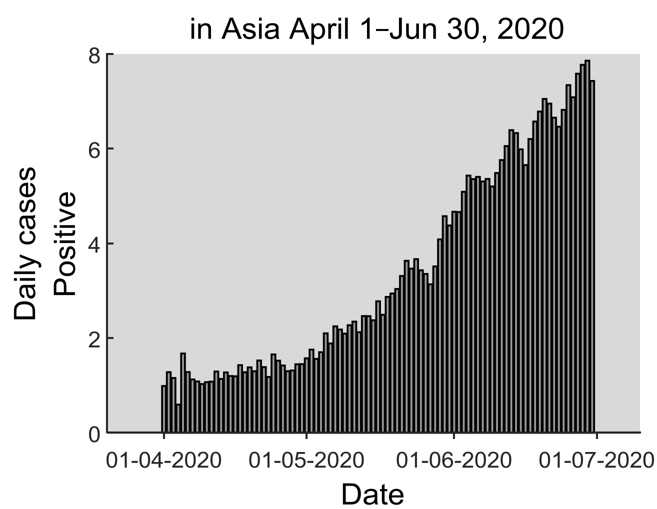

Fig. 7. New cases per million in Asia April 1-June 30, 2020.

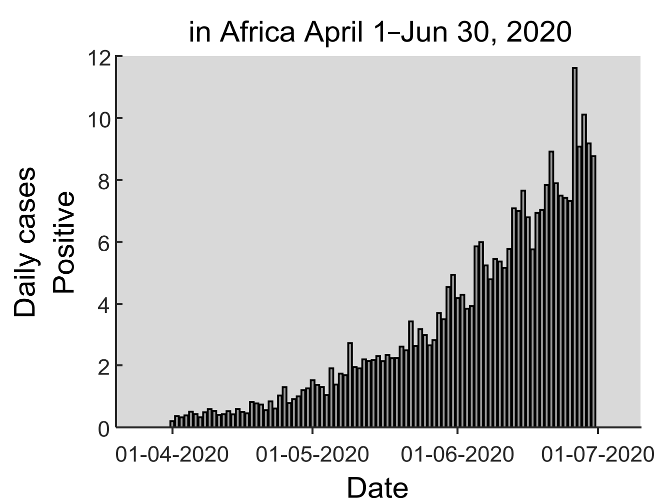

Fig. 8. New cases per million in Africa April 1-June 30, 2020.

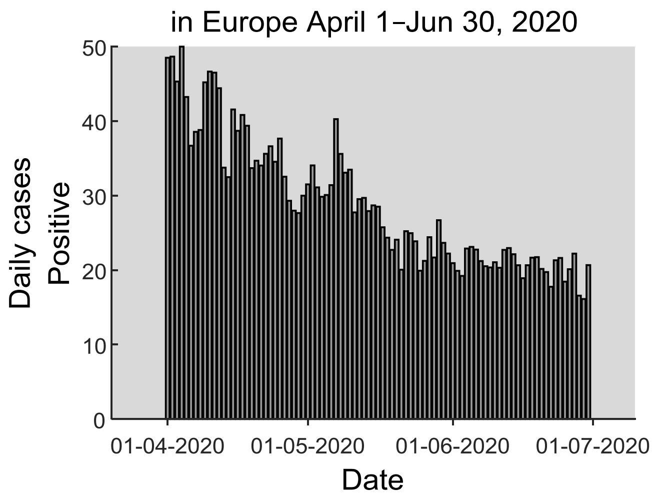

Fig. 9. New cases per million in Europe April 1-June 30, 2020.

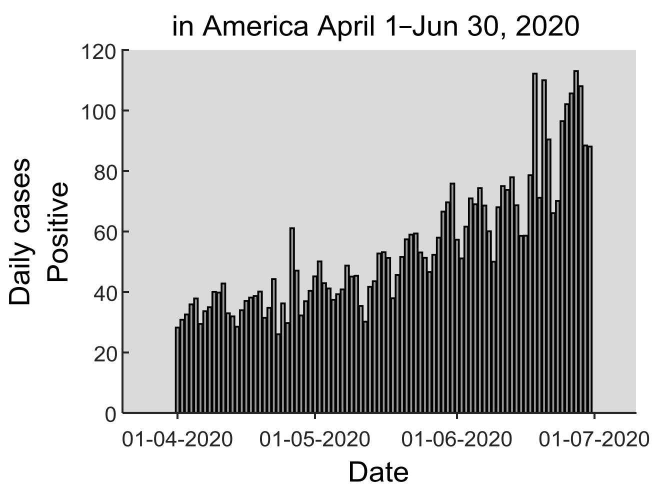

Fig. 10. New cases per million in America April 1-June 30, 2020.

point occurs on the 24th April 2020 which is about three months after the first three confirmed coronavirus cases were recorded on the 25th January 2020 in France. It appears that there are large deviations between the new confirmed cases and estimated cases in the simple logistic curve. Thus, the simple logistic curve has less of an ability to capture large daily case increases between early April and the date that the maximum growth rate occurs on the estimated curve.

We use the double logistic model to compensate the deficiency of the simple logistic model. We focus on two local extremes on the double logistic growth curve to describe the graphical outcomes. In Figs. 13 to 14, there is a sharp incline in the number of positive new cases between January 2020 and April 2020. This growth curve confirms that the virus was at its most infectious in early April 2020. Once national lockdown was imposed in March 2020, there was a sharp increase which peaked in April. The growth rate appears to fall in April and thereafter, the estimated daily number of new cases appears to decline by 43% (33600 vs 19130). This is about four weeks after the virus reached its peak at the first point of inflection following the implementation of lockdown. Since the points of inflection occurred in April and early May, many European countries started to ease national lockdown at the end of May and June 2020.

5. Conclusions

Recent work by Melnick and Ioannidis (2020), Gros (2020) and Meunier (2020) have debated over the importance of lockdown in curbing the threat of the coronavirus. As such we investigate three categories of lockdown on an international scale to assess their effectiveness against the spread of the virus. The pandemic has highlighted that there are a number of factors that influence the increase in new cases, and these include the total number of cases, underlying health conditions, population, GDP per capita, and the number of hospital beds. There has been little empirical attention given to such factors influencing the effect on new confirmed cases. This paper is aimed to act as a useful form of literature on lockdown decisions, while at the same time, emphasising the importance of such factors on a global platform.

We use the cross-sectional regression model, logistic regression model and logistic growth curve in our analysis. Our dataset is collected from the Oxford Martin School and British Broadcasting Corporation. We compare the British Broadcasting Corporation classification on lockdown in association with the stringency index to reassess the appropriateness of this classification. We find evidence that during the period March to June 2020, the total number of cases has a positive relationship to the growth of new confirmed cases. We find that this represents a reproduction rate that is an influencing factor against the number of confirmed cases which appears to decrease as the months go on. In addition, we find that as a result of lockdown, there is a negative relationship between GDP per capita and new cases. More significantly, we find that regional differences exist in the spread of the virus. In using the logistic regression model, we find strong support that Europe is approximately three times more likely to adopt a national lockdown than America. In contrast, Asia and Africa are less likely to adopt a national lockdown. As a consequence, there is a direct relationship between the reduction of confirmed cases per million and national lockdown across continents. We have therefore looked at countries which have implemented a national lockdown and compared the effectiveness of this against countries that have not implemented this measure. We focus on Europe as the majority of countries implemented a national lockdown. Our findings from the logistic growth curve reaffirm that in Europe, the daily number of new cases continuously began to decline after the first inflection point and second following the month of April.

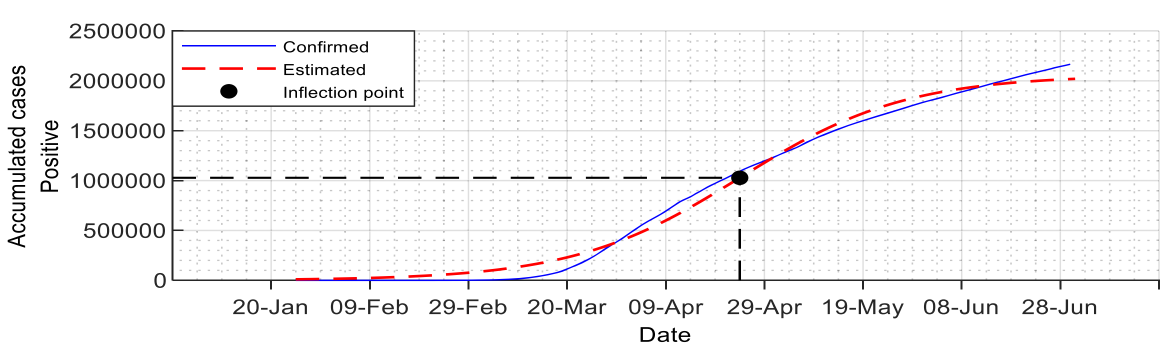

Fig. 11. Logistic growth and total cases of national lockdown in Europe January 25 - June 30, 2020.

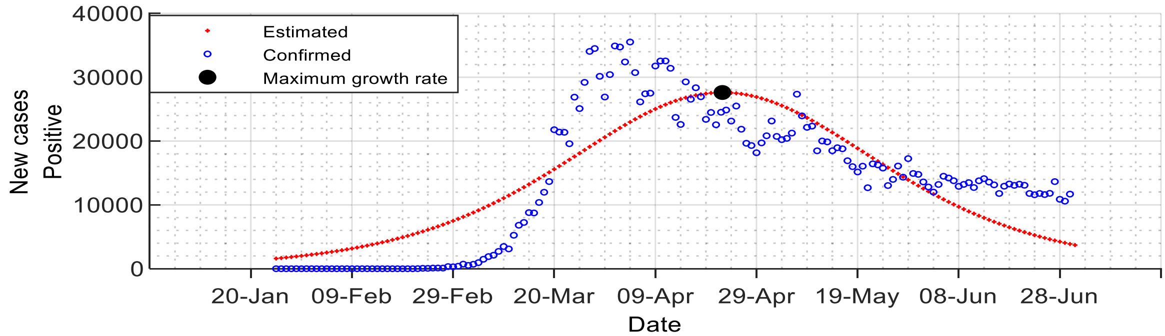

Fig. 12. Logistic growth and new cases of national lockdown in Europe January 25 - June 30, 2020.

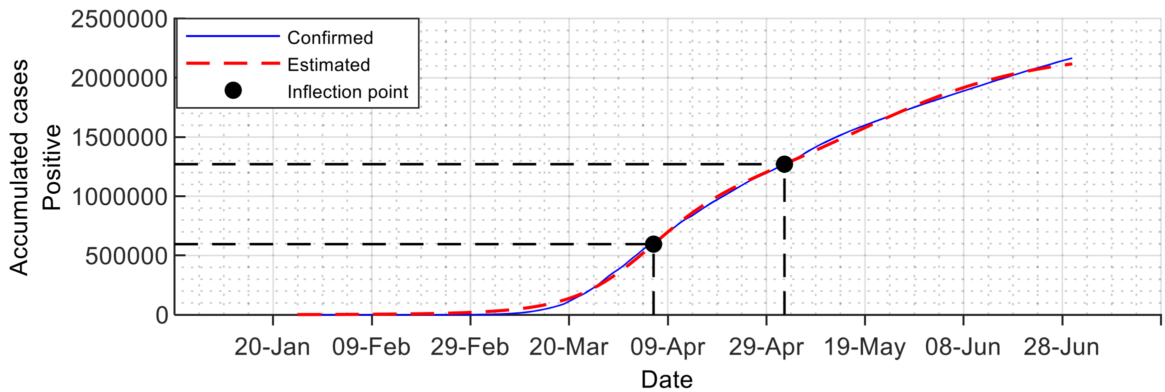

Fig. 13. Bi-logistic growth and total cases of national lockdown in Europe January 25 - June 30, 2020.

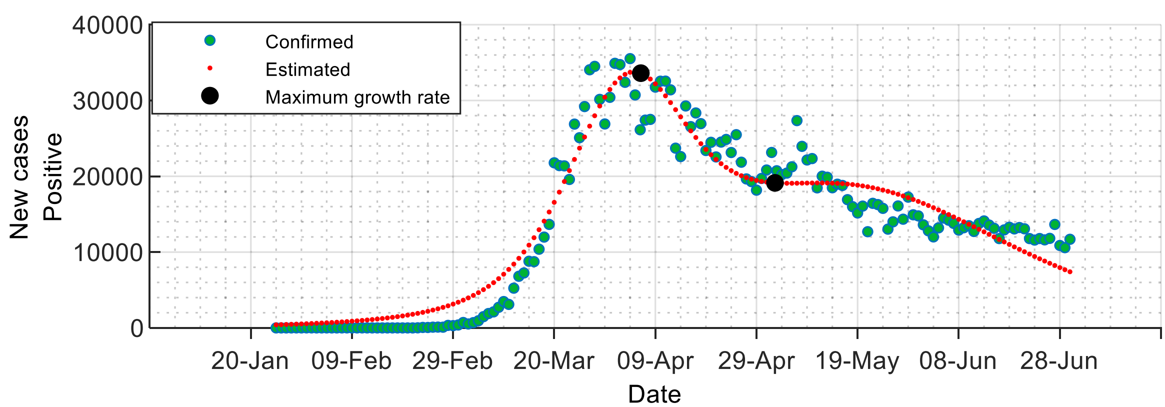

Fig. 14. Bi-logistic growth and new cases of national lockdown in Europe January 25 - June 30, 2020.

Table 9
Logistic growth curve analysis on national lockdown in Europe.

	Date	Day	Point of Inflection Estimated	Confirmed	Maximum growth rate Estimated	Confirmed
Simple	24 Apr	91	1028000	1091345	27610	23136
Double						
Point 1	6 April	73	596000	607774	33600	26138
Point 2	2 May	99	1271000	1259506	19130	23144
Maximum				2166008		35520

Simple is the three-parameter S-shaped logistic growth model. Double is the six-parameter S-shaped logistic growth model. Inflection indicates the point of inflection and growth rate indicates the maximum growth rate defined in the logistic growth curves. Date indicates the date that the point of inflection or maximum growth rate is reached. Day indicates the number of days taken to reach the point of inflection or maximum growth rate since the number of new cases was reported in Europe. Our data set shows that there were three coronavirus cases reported in France on 25th January 2020 which is the first day in the observational period. Estimated is the number of daily accumulated or new cases estimated by using the logistic growth models (Meyer, 1994; Meyer et al., 1999). Confirmed indicates the number of daily accumulated or new cases collected from countries that have imposed a national lockdown. Point 1 and point 2 indicate the first or second point of inflection and its maximum growth rate. Maximum indicates the maximum number of accumulated cases or daily new cases over the observational period.

Thus, it is important for policymakers to note that although there are economic challenges that are attached to making a lockdown decision, our analysis significantly supports that national lockdown is an appropriate safeguard in containing the virus. However, there are economic costs associated with this measure, and whether it is sustainable in the long run is subject to debate.

Appendix

Data collected on three categories of lockdown for March 2020

National	National	Local	Local	Moderate
Asia	Africa	Asia	America	Asia
Bangladesh	Angola	Afghanistan	Brazil	Bhutan
India	Congo	Australia	Canada	Brunei
Iran	Egypt	China	Chile	Cambodia
Laos	Eritrea	Indonesia	Cuba	Japan
Malaysia	Guinea-Bissau	Kazakhstan	Dominican Republic	Maldives
Nepal	Kenya	Kyrgyzstan	Guatemala	Singapore
New Zealand	Mauritius	Mongolia	United States	South Korea
Pakistan	Rwanda	Myanmar		Taiwan
Sri Lanka	South Africa	Philippines		
Uzbekistan	Uganda	Thailand		Europe
	Zimbabwe	Vietnam		Belarus
Europe				Hungary
Albania	America	Europe		Latvia
Austria	Argentina	Finland		Sweden
Belgium	Bolivia	Norway		
Bulgaria	Colombia	Ukraine		Africa
Croatia	Costa Rica			Cameroon
Czech Republic	Ecuador	Africa		Chad
Denmark	El Salvador	Benin		Equatorial Guinea
Estonia	Haiti	Burkina Faso		Gabon
France	Honduras	Central African Republic		Gambia
Germany	Panama	Cote d'Ivoire		Madagascar
Greece	Paraguay	Democratic Republic of Congo		Mozambique
Ireland	Peru	Ethiopia		Somalia
Italy	Trinidad and Tobago	Ghana		Zambia
Lithuania	Venezuela	Guinea		
Moldova		Liberia		America
Netherlands		Mali		Jamaica
Poland		Mauritania		Mexico
Portugal		Namibia		Nicaragua
Romania		Niger		Uruguay
Russia		Nigeria		
Serbia		Senegal		
Slovakia		Tanzania		
Slovenia		Togo		
Spain				
Switzerland				
United Kingdom				

National means national lockdown. Local means local lockdown. Moderate means moderate lockdown. Asia, America, Europe, and Africa indicate four continents.

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